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White Sucker 'Catostomus commersoni' Embryo Development, and Early Growth and Survival at Different Temperatures

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16 ABSTRACT

White suckers (Catostomus commersoni) were exposed from fertilization through hatching to seven constant temperatures from 6.2 through 24.1°C. High percentages of apparently normal larvae hatched at temperatures from 9.0 through 17.2°C. Maximum percent hatch occurred at 15.2°C, while only a few normal larvae were produced at 6.2°C, and none at 24.1°C.

Growth rates increased from near zero at 10.0°C to a maximum at 26.9°C. At 29.7°C growth fell below the maximum (P<0.05), and the incidence of spinal deformities was high. Death rates were uniformly low from 15.7 to 26.9°C and were significantly higher at 10.0 and 29.7°C (P<0.05). The rate of net biomass gain for test groups was maximum at 26.9°C. Net rates of biomass gain declined progressively with temperatures below 26.9°C until by 10.0°C the rate of population growth became less than the rate of weight loss through death within the population. The temperature producing maximum hatching success, 15°C, was nearly 12°C lower than that providing for maximum growth and net biomass gain.

Upper thermal 1-, 2-, and 7-day TL50 values for both newly hatched and swim-up larvae, when acclimated to 9 and 10°C, were between 28 and 29°C. When acclimated to 15 and 21°C, they were between 30 and 32°C.

Lower 1-day TL50 temperature values for both groups of larvae acclimated to 21°C were near 3°C (±2.9); 2-day TL50 values were approximately 0.5°C higher, and 7-day values were 4.8°C for newly hatched larvae and 6.1°C for swim-up larvae.

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Embryo	Tolerance	Catostomus commersoni	06 F
Juvenile	Eggs		
Larvae	Fish		
Temperature	Sucker		
Growth	White sucker		
Hatching			
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White Sucker (*Catostomus commersoni*) Embryo Development, and Early Growth and Survival at Different Temperatures

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Growth rates increased from near zero at 10.0°C to a maximum at 26.9°C. At 29.7°C growth fell below the maximum ($P < 0.05$), and the incidence of spinal deformities was high. Death rates were uniformly low from 15.7 to 26.9°C and were significantly higher at 10.0 and 29.7°C ($P < 0.05$). The rate of net biomass gain for test groups was maximum at 26.9°C. Net rates of biomass gain declined progressively with temperatures below 26.9°C until by 10.0°C the rate of population growth became less than the rate of weight loss through deaths within the population. The temperature producing maximum hatching success, 15°C, was nearly 12°C lower than that providing for maximum growth and net biomass gain.

Upper thermal 1-, 2-, and 7-day TI 50 values for both newly hatched and swim-up larvae, when acclimated to 9 and 10°C, were between 28 and 29°C. When acclimated to 15 and 21°C, they were between 30 and 32°C.

Lower 1-day TI 50 temperature values for both groups of larvae acclimated to 21°C were near 3°C (= 2.9), 2-day TI 50 values were approximately 0.5°C higher, and 7-day values were 4.8°C for newly hatched larvae and 6.1°C for swim-up larvae.

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Nous avons exposé, depuis la fécondation jusqu'à l'éclosion, des embryons de meunier noir à sept températures constantes allant de 6.2 à 24.1°C. De forts pourcentages de larves « normales » éclosent à des températures de 9.0 à 17.2°C. Le maximum d'éclosion se produit à 15.2°C, mais seulement quelques larves « normales » éclosent à 6.2°C et aucune à 24.1°C.

Les rythmes de croissance augmentent avec des températures successivement plus élevées, de près de zéro à 10.0°C à un maximum à 26.9°C. A 29.7°C, la croissance tombe au dessous du maximum ($P < 0.05$), et il se développe chez les larves une forte incidence de difformités de l'épine dorsale. Les taux de mortalité sont uniformément bas entre 15.7 et 26.9°C et sont nettement plus élevés à 10.0 et 29.7°C ($P < 0.05$). Les taux de gain net de biomasse sont à leur maximum à 26.9°C. Ils diminuent à des températures décroissantes au dessous de 26.9°C, jusqu'à ce que, à 10.0°C, le taux de croissance de la population est moindre que le taux de perte de poids par mortalité. La température produisant le meilleur éclosion, 15°C, est presque de 12°C inférieure à celle qui produit un maximum de croissance et de gain net de biomasse. Les valeurs supérieures de la TI 50 après 1, 2 et 7 jours, tant pour les larves nouvellement écloses que pour celles qui nagent vers le haut, acclimatées à 9 et 10°C, se situent entre 28 et 29°C. Lorsque acclimatées à 15 et 21°C, les larves des deux groupes d'âge ont des TI 50 après 1, 2 et 7 jours allant de 30 à 32°C. Les valeurs inférieures de la TI 50 après 1 jour pour les deux groupes de larves acclimatées à 21°C se rapprochent de 3°C (= 2.9). Les TI 50 après 2 jours sont d'environ 0.5°C plus élevées, et les valeurs après 7 jours sont de 4.8°C pour les larves nouvellement écloses et 6.1°C pour les larves nageant vers le haut.

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This report provides thermal response data for embryos of the white sucker (*Catostomus commersoni*) tolerance limits for the previously unstudied newly hatched and swim-up stages, and growth and mortality responses during their first weeks of life. Such data are essential in estimating the effects that various thermal regimes may have on the well-being of white suckers during these critical early life stages, as well as to help predict the course of interactions with fishes of natural communities.

Temperature requirements for some life stages of the white sucker have been determined previously. Raney and Webster (1942) and Raney (1945) report spawning runs from April to June, starting as temperatures reach 7.3°C, and peaks at 17.8°C. Information on adults indicates a preferred temperature of 19–21°C (Horak and Tanner 1964) and an ultimate upper lethal temperature of 29.1°C (Hart 1947). Work with juveniles has shown the upper 12-h TL50 to be 31.2°C when acclimated at 5°C (Brett 1944) and the lower 24-h TL [illegible] by 3.9 and 6.0°C when acclimated at 20 and 25°C, respectively (Hart 1947). Raney and Webster (1942) investigated the temperature tolerance of embryos but only to determine broad limits.

Materials and Methods

Mature white suckers were collected from Greenwood Lake, Cook County, Minnesota, and transported to the Environmental Research Laboratory-Duluth where the eggs were removed and fertilized using the dry fertilization technique. Laboratory fertilization was employed to insure exposure of the embryos at the sensitive stages early in development (Hokanson et al. 1973a).

Test temperatures were maintained by a continuous flow of water at constant temperatures (McCormick and Syrett 1970). Flow rates through all exposure units were 200–250 ml/min. Test temperatures were monitored with recording telethermometers which were calibrated daily with a mercury thermometer to the nearest 0.1°C. Temperatures reported are the means of once-daily thermometer readings except when temperature deviations exceeded 1.0°C for more than ½ hour, when a daily mean was calculated from the temperature recording chart. Embryo responses to test temperatures were evaluated in 1968 and 1969, three replicates in 1968 and two in 1969. Testing at 12°C, added in 1969, resulted in only two replicates at that temperature. Temperatures used in the analysis were the grand means of both years.

Test water in 1968 was carbon-filtered Lake Superior water previously treated for Duluth, Minnesota, domestic use. Carbon filtration reduced the chlorine and chloramines to a mean of 4 µg/liter, ranging from 1 to 10 µg/liter. In 1969 Lake Superior water, pumped directly from the lake became available and was used. Because the results in the 2 yr were not statistically different, ($P > 0.05$, *t*-test), the data from both years were treated together.

Embryo Survival

Treatments ranged in temperature from 6 through 24°C. Embryos from different pairs of adults were used for each of the five tests: A, B, C, D, and E (Table 1). Subsamples of embryos from each pair were randomly assigned to treatments within each replicate. In 1968 embryos were exposed directly to the test temperatures after dry fertilization without tempering or water hardening. In 1969 exposures were started with tempering at the rate of 3°C/h. To expedite placement of the embryos into test temperatures early in development, embryo sample size was first determined by volume. Enumeration followed at a less critical time. Sample sizes were lots of 100 or more except for 80 at 17.5°C, replicate D, and 97 at 9°C, replicate D. Embryos were incubated according to standard hatchery-jar procedure in 1968, but in 1969 were supported on stainless steel screens above a turbulent water discharge at the bottom of each jar (McCormick and Syrett 1970). Again, treatment effects between years were not detected ($P > 0.05$, *t*-test). During incubation, dead or infertile eggs were removed and counted daily to prevent the spread of fungus. Upon hatching, larvae were removed daily, segregated into two groups ("normal" and dead-and-deformed), and counted. Larvae were considered "normal" if obvious deformities were not observed when examined under 30× magnification. Larvae excluded from the "normal" category were those with deformities ranging from curvatures of the spine to gross distortions with various degrees of pericardial edema, smaller premature individuals with reflexed head positions and only primordial eye pigmentation (Kokurewicz 1969), and dead larvae.

Incubation results are normalized percentage values to account for the variations in sample size and percentage viability of eggs from different pairs of adult fish. Data were normalized by setting the maximum success of hatching for any replicate at 100% and all lesser degrees of success within the replicate as a percentage of that maximum. The percentage "normal" hatch data (Table 1) were converted to the arcsin $\sqrt{\text{percentage}}$ transform before statistical analysis. Analysis of variance with unequal sample size was used with Scheffe's test to account for the 12°C exposures added in 1969. Only data for "normal" larvae were analyzed, as the dead and deformed were not deemed a valid contribution to hatching success (Voiculin 1960; Kokurewicz 1969).

Larval Growth and Mortality

Rates of growth (wet weight), death, and net biomass gain (wet weight) were determined for groups of larvae reared at temperatures from 10.0 to 29.7°C (Table 2). Larvae for the main portion of the study were from a stock of embryos all incubated at 15°C. Additional lots of larvae from embryos incubated at

TABLE 1. Percentage hatch of "normal" larvae from white sucker (*Catostomus commersoni*) embryos incubated at constant temperatures.[1]

	Nominal temperatures of 1968–69 (°C)						
	6.3	9.0	11.7	15.2	17.2	20.8	24.1
1968 Test temp and results							
Mean temp (°C)[2] range	6.1 (4.3–7.8)	9.0 (8.6–9.7)		15.3 (14.9–15.6)	16.9 (11.8–17.9)	20.5 (20.2–20.9)	24.0 (23.9–24.1)
"Normal" hatch (%) replicates							
A	0.0	60.9	—	88.0	73.6	78.1	0.0
B	0.6	66.9	—	87.4	64.1	44.1	0.0
C	1.0	72.3	—	84.5	73.2	63.4	0.0
1969 Test temp and results							
Mean temp (°C)[2] range	6.1 (5.9–6.9)	9.0 (8.7–10.1)	11.7 (10.9–11.9)	15.1 (14.9–15.3)	17.6 (17.4–17.9)	21.1 (20.9–21.2)	24.2 (23.9–24.2)
"Normal" hatch (%) replicates							
D	0.0	71.1	71.4	71.0	68.8	27.9	0.0
E	0.8	35.9	54.9	66.4	47.7	39.1	0.0
"Normal" hatch (%) (means of 1968–69)	0.5	61.1	63.2	79.5	61.9	50.5	0.0

[1]Raw data, before normalization and transformation to arcsin $\sqrt{\text{percentage}}$ for statistical tests.
[2]The 95% C.I. of each year's reported mean temperatures was ±0.1°C in all cases except 1968, which was 0.6°C for 16.9°C. Confidence limits ±0.1°C are not reported because thermometer readings were no better than 0.1°C.

TABLE 2. Mean instantaneous rates (percent per day) of growth, death, and net biomass gain of young white suckers at constant temperatures for the first 4 wk after hatching. The values reported are grand means of successive weekly sampling intervals.[1]

Temp (mean, 95% C.I. and range)	Growth (wet wt)	Death	Net biomass gain (wet wt)
10.0±0.08[2] (9.7–11.3)	0.9	1.3	−0.4
15.7±0.02 (15.1–16.0)	7.4	0.2	7.2
17.9±0.03 (17.6–18.3)	9.7	0.2	9.5
20.8±0.02 (20.5–21.2)	12.0	0.1	11.8
23.9±0.01 (23.7–24.1)	13.2	0.3	13.0
26.9±0.16 (9.0–27.4)	14.8	0.3	14.5
29.7±0.11[3] (28.7–30.5)	9.2	8.3	0.9

[1]Four replicates are represented by the means reported at 15.2°, 17.9, and 20.8°C. All other represent two replicates.
[2]Values reported for 10.0°C are for a 5-wk exposure period and for 29.7°C, a 1-wk period.
[3]Vertical lines equally offset to the right of the columns join data points not found statistically different ($P > 0.05$).

9.0, 15.2, and 17.2°C were also reared at 9.0, 15.7, and 17.9°C to compare subsequent growth between fish reared at the same temperature but with different previous thermal experiences (Blaxter 1956). Paired *t*-tests failed to detect any differences due to these pretest thermal experiences ($P > 0.05$).

Eighty newly hatched larvae were counted and placed in each test unit (10 × 10 × 40.5 cm long) of the temperature-control apparatus. Feeding was ad libitum with live newly hatched brine shrimp, which remain, when not eaten, alive and available for hours within the test chambers. Brine shrimp were added in early morning, late afternoon, and whenever during the day it was noticed that most of the food had been consumed. On weekends food was introduced less frequently, only once or twice per day, but the quantity per feeding was greater. The day–night photoperiod was adjusted periodically to equal seasonal photoperiods at Duluth, Minnesota. Rearing units were cleaned daily, and dead fish were counted and removed. At weekly intervals subsamples of 10 fish per test lot were withdrawn and preserved in formalin–picric–trichloracetic solution (Ricker–Venport 1960) for later weight determinations. Sample fish were removed after overnight fasting and held an additional 6 h without food before being preserved. Weights of intact preserved fish were determined to the nearest 0.1 mg after blotting to dryness on paper toweling. Daily rates of growth, death, and net biomass gain were calculated after Ricker (1958).

Treatment effects tested were the grand mean rates of growth, death, and net biomass gain at all sampling

intervals: five weekly samples at 10°C, four at each temperature treatment from 15.7 to 26.9°C, and three at 29.7°C. The longer exposure at 10.0°C allowed these slower growing fish to reach a stage of development more nearly comparable to that attained in a shorter time by fish exposed to warmer water. Only a 3-wk exposure at 29.7°C was possible because too few fish survived at 4 wk. The exceptionally variable data for the obviously unfavourable 29.7°C treatment was excluded from analysis (to enable statistical detection of finer differences between other treatments).

Larval TL50 Temperatures

One-, 2-, and 7-day TL50 values were determined for newly hatched and swim-up larvae acclimated to 9–10, 15–16, and 21°C. The TL50s for newly hatched larvae were determined on larvae less than 24 h old, and on swim-up larvae when 50% of the population were capable of sustained swimming. The mean weight per fish was 4–5 mg when newly hatched and 5–7 mg at swim-up.

Larvae were tested in 4 × 4 × 2-in stainless steel screen-walled chambers with shallow (0.5 cm deep) glass-cup bottoms placed in test units of the temperature-control apparatus. Fish were transferred without tempering from acclimation to test temperatures. Feeding was begun after swim-up stage. Deaths were recorded, and dead fish and unused food removed daily.

The TL50 temperatures, 95% confidence limits, and slope function of the line were determined by the method of Litchfield and Wilcoxon (1949). Each time–temperature value was determined with two replicates of 10 fish each.

Results

Embryo Survival

Maximum hatch of "normal" larvae occurred at 15.2°C (79.5% success) (Table 1). Hatching success did not fall significantly below this maximum until temperatures cooler than 9.6 or warmer than 17.2°C were experienced ($P > 0.05$). Hatching took place at all test temperatures, but the number of dead and/or deformed larvae increased progressively at temperatures below and above 15.2°C. This was most evident at 6.2°C, where 99% of the larvae produced were deformed, and at 24.1°C, where all of the few larvae that did hatch were deformed.

Larval Growth and Mortality

Daily rates of growth at temperatures from 10.0 to 26.9°C increased with each higher temperature from 0.9% to 14.8%/day and then diminished abruptly at 29.7°C to 9.2%/day (Table 2, Fig. 1B). The highest absolute growth rate was at 26.9°C (14.8%/day). At 30.8°C the growth rate, 12.0%/day, was just statistically less than the maximum ($P = 0.05$). At 17.9 and 29.7°C growth was clearly below maximum, 9.7 and 9.3%/day, respectively.

Daily rates of death were uniformly low at temperatures from 15.7 to 26.9°C, ranging from 0.1 to 0.3%/day ($P > 0.05$). At 10.0°C the rate increased significantly to 1.3%/day, and at the other extreme, 29.7°C, to 8.3%/day ($P < 0.05$).

Daily rates of net biomass gain were high at 23.9 and 26.9°C, 13.0 and 14.5%/day, respectively. At 17.9°C and lower, and at 29.7°C, net biomass gain was markedly reduced from maximum. The negative rate of net biomass gain at 10°C (−0.4%/day) reflected the influence of a death rate coupled with low growth rate which removed weight from the sample population faster than the combined weight gained by survivors.

Larval TL50 Temperatures

Upper TL50 temperatures were approximately the same for newly hatched and swim-up larvae.

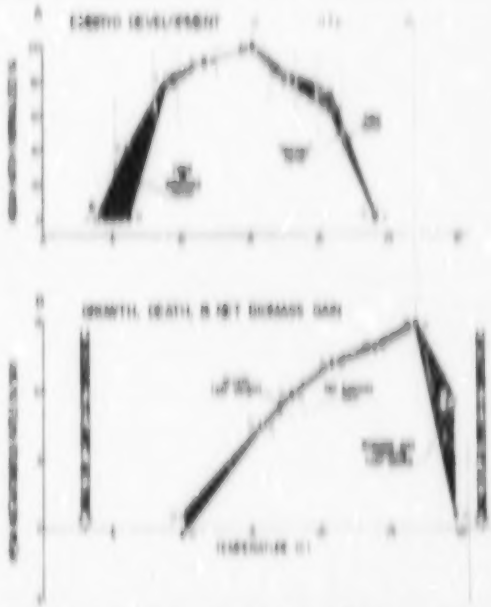

Fig. 1. A, Constant temperature effects on success of white sucker (*Catostomus commersoni*) embryo development; B, instantaneous rates of growth, death, net biomass gain, and upper and lower TL50s of larvae. Vertical bars, set off to the side of the data points, indicate the ranges of replicate means. Point a was derived from an ancillary study not described in this report.

TABLE 3. Thermal tolerance limits of white sucker larvae.

Developmental stage at start	Acclimation temp (°C)	Duration of test	TL50 temp (°C)	C.L. (95%)	Slope function
		Lower lethal temp			
Newly hatched	21.2	1-day	<2.9	—	—
		2-day	3.3	3.0–3.4	0.91
		7-day	4.8	4.2–5.1	0.83
Swim-up larvae	21.1	1-day	3.1	2.9–3.3	0.90
		2-day	3.6	b	0.94
		7-day	6.1	5.6–6.6	0.86
		Upper lethal temp			
Newly hatched	21.1	1-day	31.5	30.5–31.0	1.03
		2-day	31.0	b	1.01
		7-day	(28.3)[a]	27.7–28.7	1.08
	15.2	1-day	31.1	b	1.01
		2-day	31.0	30.3–31.8	1.02
		7-day	30.0	29.1–30.9	1.03
	8.9	1-day	29.0	b	1.02
		2-day	29.0	b	1.01
		7-day	28.6	b	1.03
Swim-up larvae	21.1	1- and 2-day	32.0	31.1–33.0	1.03
		7-day	30.5	b	1.03
	15.8	1-, 2-, and 7-day	30.7	b	1.02
	10.0	1- and 2-day	28.5	b	1.01
		7-day	29.1	27.7–28.9	1.03

[a]Questioned by authors; seems inconsistently low.
[b]Insufficient mid-range data to calculate C.L.

When acclimation was at 15–16°C and higher, the 1-, 2-, and 7-day upper TL50 values for both stages were between 30.0 and 32.0°C (Table 3). (An unexplained exception of 28.3°C for newly hatched larvae acclimated to 21°C seemed aberrantly low.) There was little, if any, increase in the upper thermal tolerance by acclimation to temperatures above 15–16°C. At 9.0–10°C acclimation, the 1-, 2-, and 7-day upper TL50 values were reduced to between 29.0 and 29.0°C, and the 7-day TL50 values tend to be a few tenths of a degree lower than for the shorter exposures.

The two larval stages when acclimated to 21°C showed little difference in lower thermal tolerance. The 1- and 2-day lower TL50 values ranged from less than 2.9, the lowest test temperature, to 3.6°C. Seven-day lower thermal TL50 values were 4.8°C for newly hatched larvae and 6.1°C for swim-up larvae. The TL50 values of fish acclimated to 15°C and lower were below the minimum tested temperature.

Other Effects

Spinal deformities were observed in three successive lots of larvae initially reared at 15°C and subsequently transferred to 10°C for 2 wk. Fish in all three lots experienced high death rates, and 100% spinal deformities among survivors. Deaths subsided when survivors were returned to lower temperatures, but spinal curvatures persisted.

Observations also showed that larval suckers avoid temperatures determined to be unfavorable to sustained growth and survival. In all rearing units where water temperatures were 27°C and lower, swim-up larvae were more concentrated at the water input end of the tanks; however, in a 31.2°C test unit used for TL50 testing, larvae were found at the cooler discharge end. Avoidance of temperatures in excess of 31.2°C was a chance discovery when greatly contrasting ambient temperatures resulted in a thermal gradient (31.2–31.4°C) from the water input end of a rearing unit to the discharge end. The ability of fishes to detect and respond to temperature differences of this magnitude has previously been reported (Hull 1936).

Discussion

As the thermal responses of the various life stages of the white sucker investigated in this study are contemplated, a marked parallel becomes apparent between the temperatures at

which each life stage occurs in its natural environment and those at which the particular stage has been found to prosper in the laboratory. The first thermal experience of the new individual begins with the fertilization of the egg, an event that takes place in relation to a number of naturally occurring precursors, among which are lengthening daylight hours, a run into spawning areas (usually tributary streams, or shallows of lakes or streams), and a warming trend as the spring season advances.

Raney and Webster (1942) reported spawning runs of white suckers commence as water temperatures reached and exceeded 7.2°C. Initiation of spawning runs at 7.2°C can be interpreted to indicate that naturally spawned embryos would be expected at or above that temperature, so long as seasonal thermal trends persist. Our data indicate that such spawning temperatures would be near the minimum thermal limits for the success of embryos. Viewed in the evolutionary sense, such would suggest that natural selection may have eliminated those individuals possessing genetic traits leading to spawning at lower temperatures. Maximum incubation success in our study occurred at 15.2°C. Raney (1943) observed peak spawning activity at 17.8°C. Both of these temperatures are similar, and cool enough to allow several degrees of warming during the days of incubation without exceeding the ~20.8 but ~24.1°C tolerance limit for developing embryos. Net rate of biomass gain during the larvae–juvenile stages was relatively poor at 15.2, while the maximum rate was found at 26.9°C. From these observations the importance of a number of interrelated naturally occurring factors becomes more apparent.

No one temperature is best for all life stages of white sucker. There is an 11.7°C increase in temperature between that resulting in greatest success in hatching of embryos and that resulting in most rapid net gain in larval–juvenile weight. That such a trend would be expected comes from the recognition that spawning is in the spring in shallow water where the time between spawning and juvenile growth would be expected to produce several degrees of temperature rise between the occurrence of the two life stages. A further example of the way the sucker has adapted to the restraints of its environment is seen in the movements of young suckers to warmer shallows of lakes and streams (Reighard 1915; Hunstman 1935) apparently taking advantage of the most nearly optimum of available temperatures. Yet these same individuals can be expected to leave these warmer waters when heating results in temperatures exceeding those for their well-being. Our study showed that avoidance would be expected when young suckers encounter waters of 31.3°C and above. Huntsman (1946) observed thermal kills of young suckers when unseasonal temperatures in a Nova Scotia stream reached 31.4°C.

All of these responses indicate an intricate meshing of the organism and the natural conditions in its native habitat. With such an interdependence, the importance of maintaining seasonal temperature cycles, access to native spawning sites, and access to thermal retreats during periods of excessive temperatures becomes apparent.

Aside from the insights gained in this study as it applies directly to white sucker, another use lies in its potential aid to the fish manager interested in promoting the well-being of other species such as trout cohabiting natural waters with suckers.

Trout, it would seem, prosper in cold waters not so much because cold water is good for them, but possibly more because they are more capable of coping with the cold than are their competitors (Vincent and Miller 1969; Bowen and Coutant 1971). Thus, temperatures reported as optimum for trout when derived from studies where the trout were studied independent of other species (McCormick et al. 1972; Hokanson et al. 1973b) may promote natural competitors such as suckers by tipping the interspecific competitive advantage in favor of the more warmwater competent species. Consequently, when the well-being of trout is sought in a mixed trout–sucker population it may be advantageous to manage the habitat for temperatures so as to limit the success of competing indigenous suckers.

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